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Copepod community along the Mediterranean coast of Morocco (Southwestern Alboran Sea) during spring

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Abstract

Copepod community along the Mediterranean Moroccan coast was investigated, for the first time, during April 2013. Total abundance varied from 53 to 4557 ind. m^{-3} and high values were found in coastal waters. *Oithona nana* and *Paracalanus parvus* dominated in the entire area and species diversity was decreasing from the West to the East. Hierarchical clustering revealed three groups of stations, depending on their geographic position (western, central and eastern areas). Indicator species analysis pointed out that *Clausocalanus furcatus* and *Gaetanus* sp. were significantly associated with Group I, *Clausocalanus* sp.*, Centropages* sp. and *Centropages chierchiae* with Group II, whereas *Temora longicornis* was significantly associated with Group III. Detrended Correspondence Analysis based on the species abundance and environmental variables (temperature, salinity, chlorophyll-a), highlighted a more or less similar setting of stations which was related to salinity and temperature. The presence of three anticyclonic gyres at the northern part of the study area is suggested as the major factor acting on the variability of copepod community along the Mediterranean Moroccan coast.

Keywords: Copepods, south western Mediterranean, Indicator species, coastal, offshore.

Introduction

The Moroccan Mediterranean coast is a part of the Alboran Sea, in the south western basin of the Mediterranean Sea. Its hydrology is characterized by the water exchange through the Strait of Gibraltar and the presence of two anticyclones gyres: the Western Alboran Gyre and the Eastern Alboran Gyre, conferring specific properties to this part of the Mediterranean Sea (Vargas-Yàñez *et al*., 2002). These properties determine the trophic state of the coastal area through the elevated concentration of nutrients, and promote a considerable biological diversity especially in terms of fisheries resources, where significant fishing activity is generated (Papaconstantinou & Farrugio, 2000).

Zooplankton communities play a key role in the ecological balance of all ecosystems and are good indicators of climate changes (Hays *et al*., 2005). An overview of the plankton studies conducted during the last 25 years in the epipelagic offshore waters of the Mediterranean Sea, revealed ~~a~~ considerable spatial variability (Siokou-Frangou *et al*., 2010). However, zooplankton studies in-the Southern Mediterranean are strongly limited (Riandey *et al*., 2005; Khelifi-Touhami *et al*., 2007; Zakaria, 2006; Ounissi *et al*., 2016) when compared to those in the Northern Mediterranean (e.g. Alcaraz *et al*., 2007; Fernandez de Puelles *et al*., 2007; Raybaud *et al*., 2008; García-Comas *et al*., 2011; Mazzocchi *et al*., 2011).

This is the first study of the copepod community in the Moroccan Mediterranean coast. An attempt was made to investigate possible relationships between environmental parameters and zooplankton communities necessary for understanding the dynamics of pelagic ecosystems in the Mediterranean Sea. However, mechanisms driving the relationships between environmental factors and copepod populations should be addressed when combining field time series and laboratory studies (Christou, 1998).

Material and Methods

Samples Collection and Analysis

An oceanographic survey was conducted in April 2013 along the Moroccan Mediterranean coast and a total of 61 stations (out of a total of 70 stations sampled for hydrological parameters) were sampled. These were located between the coast and the 500m isobath (Supp. data Fig. S1). Zooplankton was collected by oblique hauls from 0 to 100 m depth and to the bottom in shallower waters, using a 147μm net of a 20 cm diameter. The filtered water volume was measured by a flow meter fixed in the net opening. Copepods were identified and counted and their abundance estimated as number of individuals per cubic meter.

Surface temperature and salinity were measured by CTD (Type Rinko), and surface chlorophyll-a was estimated from water samples collected by the 1L-Niskin bottles and analyzed using a fluorometer 10-AU.

Data analysis

At each station, species richness (*S*) and Shannon-Wiener diversity index (*H'*) were estimated. Shannon-Wiener diversity index (*H'*) was computed on log2 basis.

Hierarchical Clustering and MDS (Multi Dimensional Scaling) analyses were employed for grouping of stations, based on the similar species composition (Teer Brak & Prentice, 1988) using PRIMER (version. V); the Bray-Curtis similarity index was used.

Detrended Correspondence Analysis (DCA) was performed to investigate the relationship between environmental variables and copepod community composition in sampling stations. Environmental variables used in the ordination diagram were: surface Temperature (T), surface Salinity (Sal) and Chlorophyll-a surface concentration (Chl). Only species with relative abundance more than 0.1% were included in this analysis. The abundances were log (X+1) transformed to reduce the effect of the copepod patchiness.

Indicator species analysis (Dufrêne & Legendre, 1997) was conducted to find potential indicator species for particular environmental conditions (station groups obtained by the hierarchical clustering). Indicator Value ($I_{ND}V_{AL}$) for each species *i* in the group *j* were computed using the following equation:

$$I_{ND}V_{ALij} = RA_{ij} \text{ x } RF_{ij} \text{ x } 100$$

RA_{ij} and RF_{ij} are respectively the relative abundance and the relative occurrence for species *i* in group *j*. A threshold $I_{ND}V_{AL} \geq 25\%$ and $p<0.05$ were used as a cutoff for the indicator species (Dufrêne & Legendre, 1997).

For all data analysis, the station 33 was not considered because the measured copepod abundance was very low. All statistical analysis was conducted using R software (R Development Core Team, 2013).

Results

In April 2013, the spatial variations of surface temperature and salinity were low along the survey area (average: 17.02 ± 0.35°C and 36.57 ± 0.2, respectively). However, an increase from the west to the east was observed for both parameters (Supp. Data Fig. S2). Chlorophyll-a surface concentrations did not exceed $0.5\mu gl^{-1}$. With the exception of the highest concentration offshore Cape of three Forks (st 61), the higher concentrations were mainly recorded at the western coastal stations, corresponding to the basins of major rivers in the region (Supp. Data Figs. S1 and S2).

Copepods were the major zooplankton component in all samples (78% of total zooplankton abundance); among them 65% were adults, 16% copepodites and 19% nauplii. Total abundance of copepods ranged from 53 to 4557 ind. m^{-3} with an average abundance of 1152 ind. m^{-3}. In general, the highest abundances were recorded at the coastal stations (Fig. 1). High values (higher than 2500 ind. m^{-3}) were found at a few stations mainly located in the western area, where the maximum abundances were recorded at two offshore stations: st 7 (4557 ind. m^{-3}) and st 10 (4441 ind. m^{-3}). The lowest abundances were found at stations st 3 and st 4, located in the western limit of the study area (near the Strait of Gibraltar, 53 and 79 ind. m^{-3} respectively) as well as at stations st 33 and st 45, positioned in the central area (11 and 67 ind. m^{-3} respectively).

In total, 58 species belonging to 21 families were identified (Supp. Data Table S1). Two species dominated the copepod community: *Oithona nana* (21.47%) and *Paracalanus parvus* (21.32%), with a 100% occurrence along the Moroccan Mediterranean coast. Both species highly dominated at the stations of maximum copepod abundance, namely at st 7 and st 10 (*P. parvus*: 921 and 918 ind. m^{-3} respectively and *O. nana*: 1067 and 918 ind.

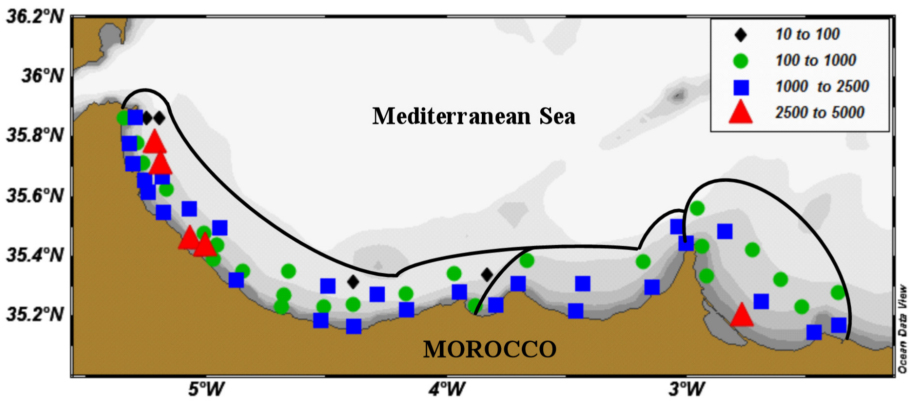

Fig. 1: Distribution of copepod abundance (ind. m^{-3}) collected during April 2013 along the Moroccan Mediterranean coast. The 3 groups from MDS results are projected.

m^{-3} respectively). *Oncaea venusta* and *Euterpina acutifrons* also occurred at all stations (100% occurrence) but with low relative abundance (6 and 4% respectively).

The presence of *Acartia clausi, Clausocalanus arcuicornis, Centropages typicus, Eucalanus hyalinus and Temora stylifera* was quite important, without any distinct distribution pattern. *Calanus helgolandicus* and *Temora longicornis* occurred mostly in the most western and eastern sites with variable abundance, while *Centropages chierchiae* and *Labidocera wollastoni* were found with low abundance in a restricted area of the western region.

Species richness followed an eastward gradual decrease (Supp. Data Fig. S3). The highest species numbers (> 30 species) were recorded in the western region (st 27, 30, 31) and the minimum (7 species) was found in the eastern region, offshore of Cape of three Forks (st 59), as a limit between these two regions. Shannon-Wiener index values, varying between 1.97 and 3.96 bits, showed a similar eastward decreasing trend (Supp. Data Fig. S3).

Hierarchical clustering indicated three groups of stations at 60% similarity level that were represented in the MDS plot (Supp. Data Fig. S4). These groups corresponded to three geographical areas: Group I included 39 stations (1 - 46), positioned at the western part of study area, plus st 52. The eastern part was differentiated in two groups separated by the Cape of three Forks: Group II (8 stations) and Group III (13 stations) (Supp. Data Figs S1 and S4).

The results of the Detrended Correspondence Analysis (DCA) are presented as plot of stations against the first two axes (Fig. 2). DCA shows a discrimination of the easternmost stations (those included in Group III of the hierarchical clustering) from those of the central area along the first axis. Along the second axis, stations localized in the west of Cape of three Forks (those included in Group II of the hierarchical clustering) are discriminated from those positioned in the western part (corresponding to Group I of the hierarchical clustering).

When the environmental variables were projected on the DCA plot, the first axis was well correlated with salinity (r = 0.919), while a low correlation was found with the second axis (-0.394). Temperature contributed significantly to the formation of the two axes (r = -0.636 and 0.772, respectively). The discrimination of stations along the first axis was related to the salinity (high values in the easternmost part), while the discrimination of stations along both axes was related to temperature.

Supp. Data Table S2 includes the results of the indicator species analysis for the three groups. From the nine copepods characterizing Group I, only *Clausocalanus furcatus* and *Gaetanus* sp. were significantly associated with it. *Clausocalanus* sp., *Centropages* sp. and *Centropages chierchiae* were the indicator species significantly associat-

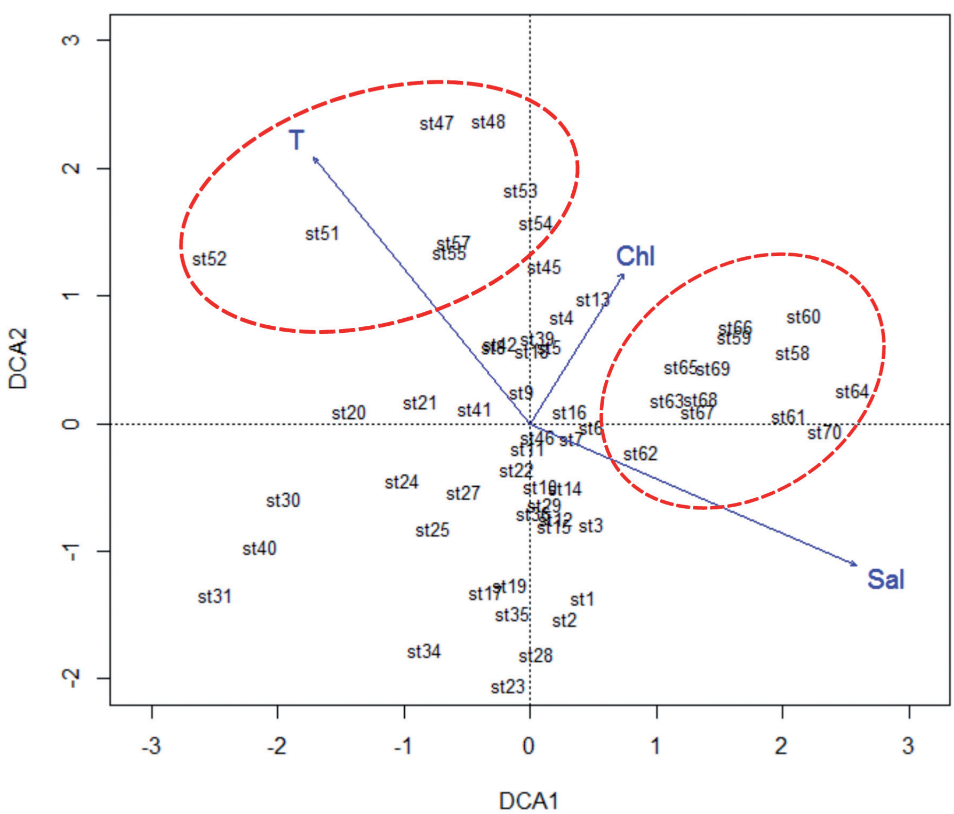

Fig. 2: Detrended Correspondence Analysis (DCA) ordination of sampling stations with the environmental variables (T: sea surface temperature, Sal: sea surface salinity and Chl: chlorophyll-a surface concentration). Dashed line indicates Groups III and II from MDS plot (Supp. Data Fig. S4).

ed with Group II. Group III was characterized by four copepods, but only *Temora longicornis* contributed significantly.

Discussion

The study area is traversed by a large number of rivers, particularly in the western part, enhancing the biological production of the coastal area, which is in accordance with the fact that the highest copepod abundances were mostly recorded at coastal stations, especially in the western area. In general, zooplankton abundance is higher in neritic than in oceanic waters (Champalbert, 1996; Fernandez de Puelles *et al*., 2003).

The inflow of Atlantic water, may explain the presence of some rare species (Youssara & Gaudy, 2001; Zaafa *et al*., 2012). As an example, *Centropages chierchiae* was recorded only in a few stations. This species is known in tropical and subtropical waters and considered as an indicator of Atlantic upwelling water (Fiùza, 1983; Sobrinho-Gonçalves *et al*., 2013). In the Mediterranean Sea, its distribution is limited to the western part (Razouls *et al*., 2005-2016) influenced by the Atlantic flow. According to 2006-2007 data, among the 103 species recorded at two transects on both sides of the Gibraltar Strait, 61.2% were common in both sectors, whereas 21.4% and 17.5% were endemic to the Atlantic Ocean and the Mediterranean Sea respectively (Zaafa *et al*., 2012).

The most abundant species found in the study area, such as *Paracalanus parvus, Oithona nana, Acartia clausi, Clausocalanus arcuicornis, Centropages typicus* and *Temora stylifera* are commonly found in the western Mediterranean Sea (Gaudy, 1985). According to Siokou-Frangou *et al.* (2010), the dominance of the small-sized copepods (such as *Clausocalanus, Calocalanus*, *Oithona*, oncaeidae and corycaeidae) represents the major feature of the structure of mesozooplankton communities in the Mediterranean Sea and contribute mostly to species abundance and diversity in samples collected by nets with small mesh size. Furthermore, the species *Acartia clausi, Centropages typicus, Paracalanus parvus* and *Temora stylifera* are considered as key species, accounting for a large part of total copepod abundance from spring to autumn and display a common succession pattern throughout the Mediterranean Sea (Fernandez de Puelles *et al*., 2007; Fernandez de Puelles *et al*., 2009; Saiz *et al*., 2013).

Numerous studies conducted in the Alboran Sea have highlighted the impact of anticyclonic gyres not only on its physical oceanography, but also on its biological productivity (Rodriguez *et al*., 1994; Rubin *et al*., 1995). The flowing of Atlantic current southern of the Alboran Island, leads to an increase of salinity and inversely to a decrease of temperature, contributing to the activity of the two anticyclonic gyres: Western Anticyclonic Gyre (WAG) and Eastern Anticyclonic Gyre (EAG) (Vargas-Yàñez *et al*., 2002; Renault *et al*., 2012). However, according to Renault *et al*. (2012), the winter-spring phase is characterized by two gyral scale features: the well-known WAG within the western area and the Central Cyclonic Gyre (CCG), a new structure not identified in former studies, occupying the central and eastern parts of the Alboran Sea. According to the same authors, a double anticyclonic gyre regime constitutes the stable circulation system of the summer-autumn period when the EAG is formed within the eastern Alboran basin, whereas in this case, the CCG is narrower and located closer to the WAG.

Taking into account the above information and based on the satellite images of the average SST and chlorophyll-a, during our sampling period (Supp. Data Fig. S5), we may assume a probable corresponding between the three groups of stations and the local hydrological regime. According to those images, CCG seems to be in an initial formation stage. Indeed, in the western part (west of Al Hoceima) the water was cooler and less salty, which could correspond to the development of WAG in April (Vargas-Yàñez *et al*. 2002). Eastwards, temperature and salinity were higher in the two areas separated by the Cape of three Forks which could be related with the presence of CCG and EAG respectively. Finally, it appears that Groups I, II and III, are attached to the southern parts of WAG, CCG and EAG, one-to-one.

The individualization of the three copepod community groups in April 2013 along the southern part of the Western Mediterranean Sea was a consequence of the hydrological conditions, indicating some important biological variability. This was further justified by the significant presence of indicator species characterizing each group, even with low abundance. The major impact of temperature and salinity on the copepod associations was also highlighted, supporting the fact that the Mediterranean Moroccan coast, as part of the Alboran Sea, is a very dynamic and contrasted ecosystem (Renault *et al*., 2012; Saiz *et al*., 2013). Finally, more work in other seasons is necessary to reveal the mechanisms controlling biological variability at this part of the Mediterranean Sea.

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